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SOLID STATE IMPATT AMPLIFIERS PERFORMANCE DATA

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16. Abstract

Evaluation data on an 8-watt and a 16-watt Impatt Amplifier are presented to concisely describe the performance of these amplifiers. The data include component specifications and photographs, TSC test set-up configuration, amplitude and phase characteristics of the input and/or output, and noise data.

The amplifier development effort was pursued in the component development phase of the Microwave Landing System (MLS) Program, because solid state sources are considered a part of the critical technology ultimately required for the MLS systems.

The units performed satisfactorily and show promise for the implementation of this solid state source technology into future microwave landing systems.

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PREFACE

The amplifiers described herein are part of the component development phase of the Microwave Landing System Program sponsored by the Systems Research and Development Service of the FAA. These components were designed and built for the Department of Transportation, Transportation Systems Center by Stanford Research Institute (SRI) under Contract DOT-TSC-158, which was monitored and guided by the author. The author wishes to thank Drs. Don Parker and Robert E. Lee of SRI for their cooperation and for the use of some of the contract data which is reproduced herein.

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1. INTRODUCTION

Moderate transmitting power on the order of 2 to 20 watts will probably be required for a Microwave Landing System (MLS). Two solid state Impatt Amplifiers were designed and built by Stanford Research Institute (SRI), Menlo Park, CA on Contract DOT-TSC-158, administered and monitored at the DOT/Transportation Systems Center, Cambridge, MA. One unit, an 8-watt amplifier utilizing 4 diodes, was obtained on the original contract. A second unit, a 16-watt amplifier utilizing 12 diodes, was obtained on a contract extension. The design and fabrication of these solid state amplifiers was pursued as part of the component development phase of the Microwave Landing System Program. It is felt that they are a part of the critical technology required to produce reliable, long life, and ultimately inexpensive microwave landing systems.

2. EIGHT-WATT AMPLIFIER

The 8-watt amplifier utilizes 4 diodes and a hybrid-circuit power-combiner scheme to combine the outputs from the individual avalanche diodes, each of which is mounted in its own coaxial matching circuit and heat sink. The four diode amplifier produced approximately 6dB gain and 4 1/2 percent power-added efficiency at an output level of approximately 8 watts in the 5.25 GHz frequency range. Output power of approximately 10 watts can be obtained with a somewhat improved efficiency but reduced gain of about 4dB. The basic amplifier requirements are listed in Table 1. A photograph of the unit is shown in Figure 1. The TSC test system for evaluating the amplifier is presented in a photograph, Figure 2, and a block diagram, Figure 3.

Input and output data are presented as a function of frequency in Figure 4. The input and output responses for 1 watt are labeled as P1 in and P1 out, respectively. The other power levels are labeled accordingly. The small discontinuity in the response at about 5200 MHz was not present during earlier data taken at TSC and is probably due to a slight instability. In Figures 5 and 6, the gain linearity and compression characteristics, respectively, of the amplifier are presented. Figure 5 presents a family of curves at 5 frequencies from 5200 to 5300 MHz which depict output characteristics from 0 to 5 watts with input power levels from 0 to 1.2 watts. The two curves having better linearity are near the band center at 5250 and 5270 MHz. Figure 6 presents another family of curves at the same frequencies for output and input power levels of 0 to 12 and 0 to 5 watts, respectively. Gain compression at 5230 and 5250 MHz occurs at about 5.5 watts output which corresponds to an input power level of about 1 watt. Figures 7 and 8 present output phase change as a function of input power and output power levels, respectively. At 1 watt input, Figure 7 indicates a 4 deg/dB phase characteristic. This is somewhat higher than the 1.5 deg/dB maximum claimed by Hughes Electron Dynamics Division for a TWT operated as a wideband, low distortion amplifier. The photographs in Figures

9a and b illustrate the noise free character of the impatt amplifier output signal relative to the input signal. These pictures indicate negligible noise at 70dB below the peak signal level. The data for Figures 10, 11 and 12 were obtained at SRI. Figure 10 indicates the output phase sensitivity of the four-diode amplifier to a supply voltage variation of 150-164 volts. Figure 11 presents the gain variation with output power at three frequencies. According to the data, 6dB gain and 8 watts output power are achieved with 5 percent efficiency at 5.249 GHz. Figure 12 presents the FM and AM noise of a low noise klystron driver compared to the four-diode impatt amplifier-driver combination. Figure 12a is a plot of FM noise, in a 1 KHz band, displaced from 2 to 100 KHz from the carrier frequency of 5.4 GHz. Figure 12b is a plot of AM noise, also in a 1 KHz band, from 2 to 100 KHz displacement from the carrier. Negligible FM noise is added by the impatt amplifier. Considerable AM noise, at $\frac{1}{f}$ rate, is added as the displacement decreases toward the 1 KHz displacement frequency.

Finally, Table 2 presents some measured FM distortion data for the four-diode amplifier at the 8-watt output level. The FM distortion is equal to or less than 2 percent for modulation indices at or below 1.4.

Additional in-depth detail is included in SRI's final report, "Theoretical and Development Work on High-Efficiency Avalanche Diode Sources".[1]

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[1]Lee, R. E., Parker D., Gysel U. H., Podell A. F., Theoretical and Development Work on High-Efficiency Avalanche Diode Sources, Stanford Research Institute, Menlo Park CA, Final Report September 1972.

3. SIXTEEN-WATT AMPLIFIER

The 16-watt amplifier utilizes 12 diodes and hybrid-circuit combiners of the type used in the 8-watt amplifier. Two of the amplifier-combiners serve the same function as the one in the 8-watt unit. The third amplifier-combiner uses 4 diodes and serves as a dual driver for each of the succeeding two amplifying segments. Each individual amplifier is fabricated in microstrip rather than in coax. This provides the advantages of lower cost and better reproducibility. A photograph of the 16-watt amplifier is shown in Figure 13. The specifications are included as Table 3.

Figure 14 presents the output power levels for input levels of 0.5 to 2.5 watts across the frequency band of 5.0 to 5.35 GHz. Gain compression characteristics at four frequencies are shown in Figure 15. Output levels range up to 16 watts for input power levels up to 2.5 watts. Figure 16 demonstrates the phase shift through the amplifier at various input levels up to 1 watt. Figures 17 and 18 illustrate the AM and FM noise performance of the Impatt Amplifier in a 1 KHz measurement bandwidth. Figure 17 presents the FM noise compared to a klystron oscillator and to a 10-watt traveling wave tube amplifier. The noise of the Impatt Amplifier is within 3 Hz of the klystron or TWT over the entire measurement range of 2 to 100 KHz. Figure 18 illustrates the AM noise of the Impatt Amplifier compared to the klystron driver. Although the AM noise is higher, it remains at a flat level of 125 dB below the carrier from 5 KHz to the end of the measurement range at 100 KHz.

4. SUMMARY

Two moderately high power CW Impatt Amplifiers have been developed for the DOT/Transportation Systems Center by Stanford Research Institute on Contract DOT-TSC-158. Performance data on both of these units is presented in this report. Additional in-depth detail has been presented in SRI's Final Report titled "Theoretical and Development Work on High-Efficiency Avalanche Diode Sources."

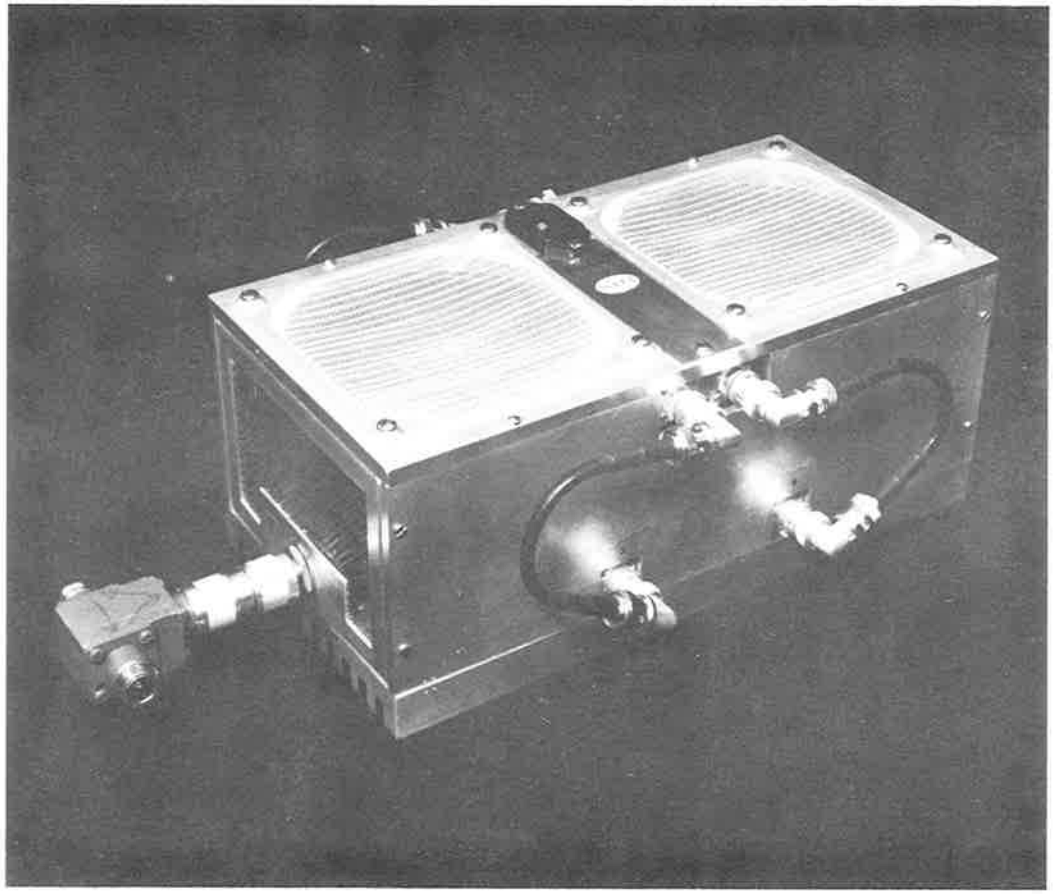


Figure 1 Four-Diode Amplifier

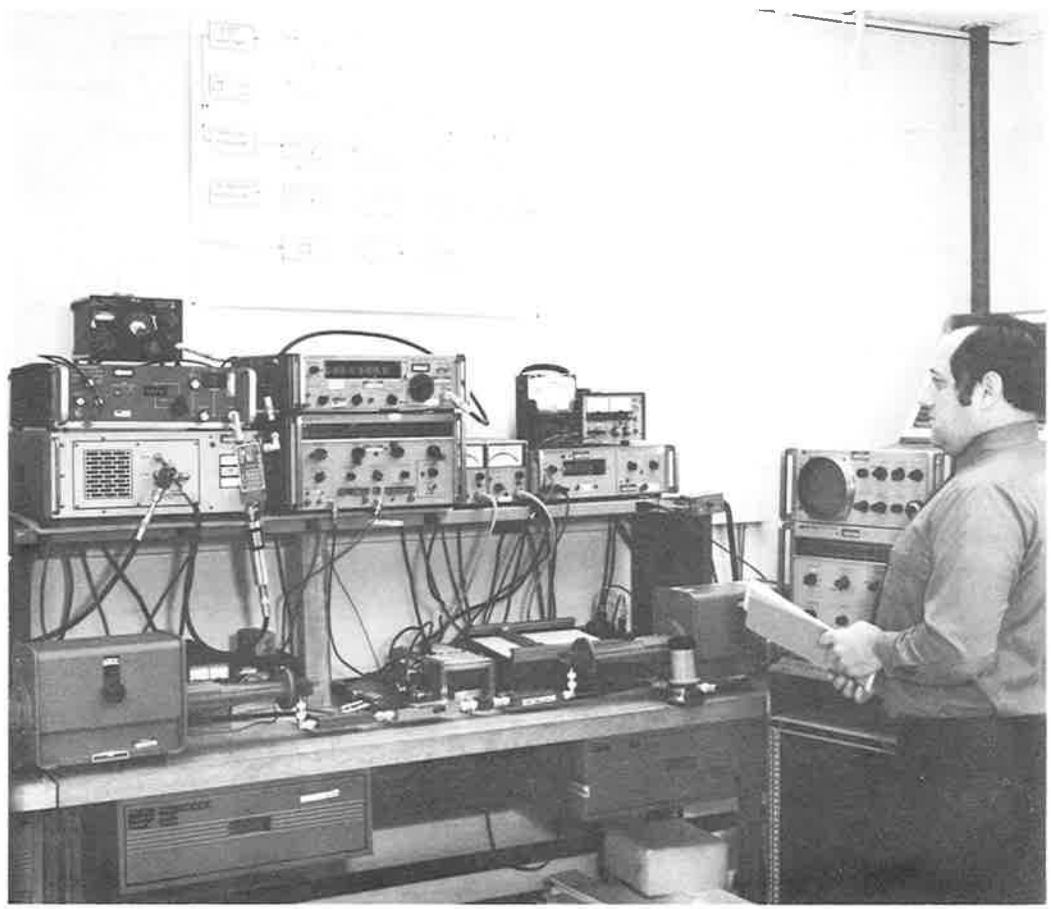


Figure 2 Impatt Amplifier Evaluation Test Set-Up

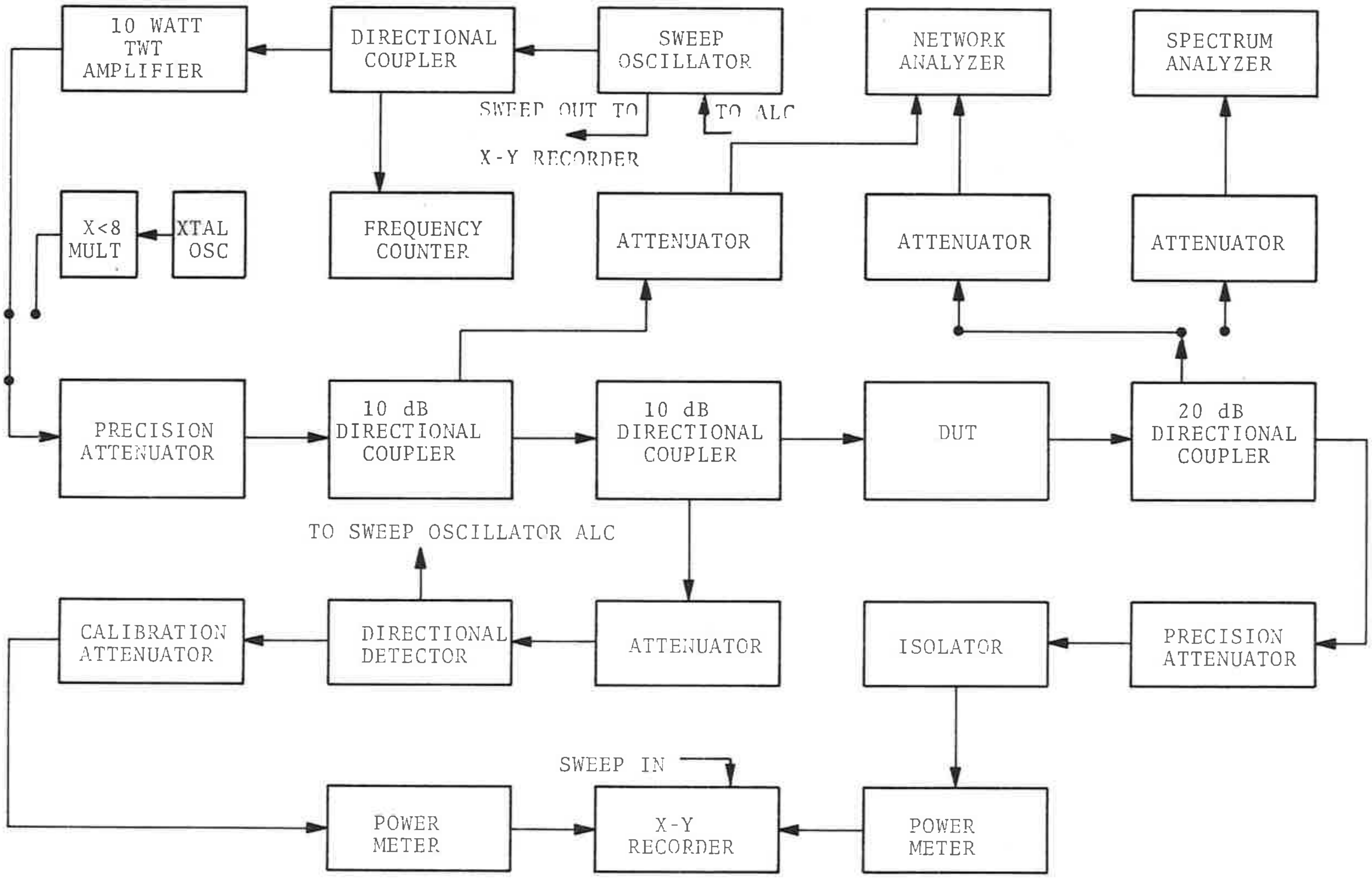


Figure 3 Block Diagram-Impatt Amplifier Evaluation Test Set-Up

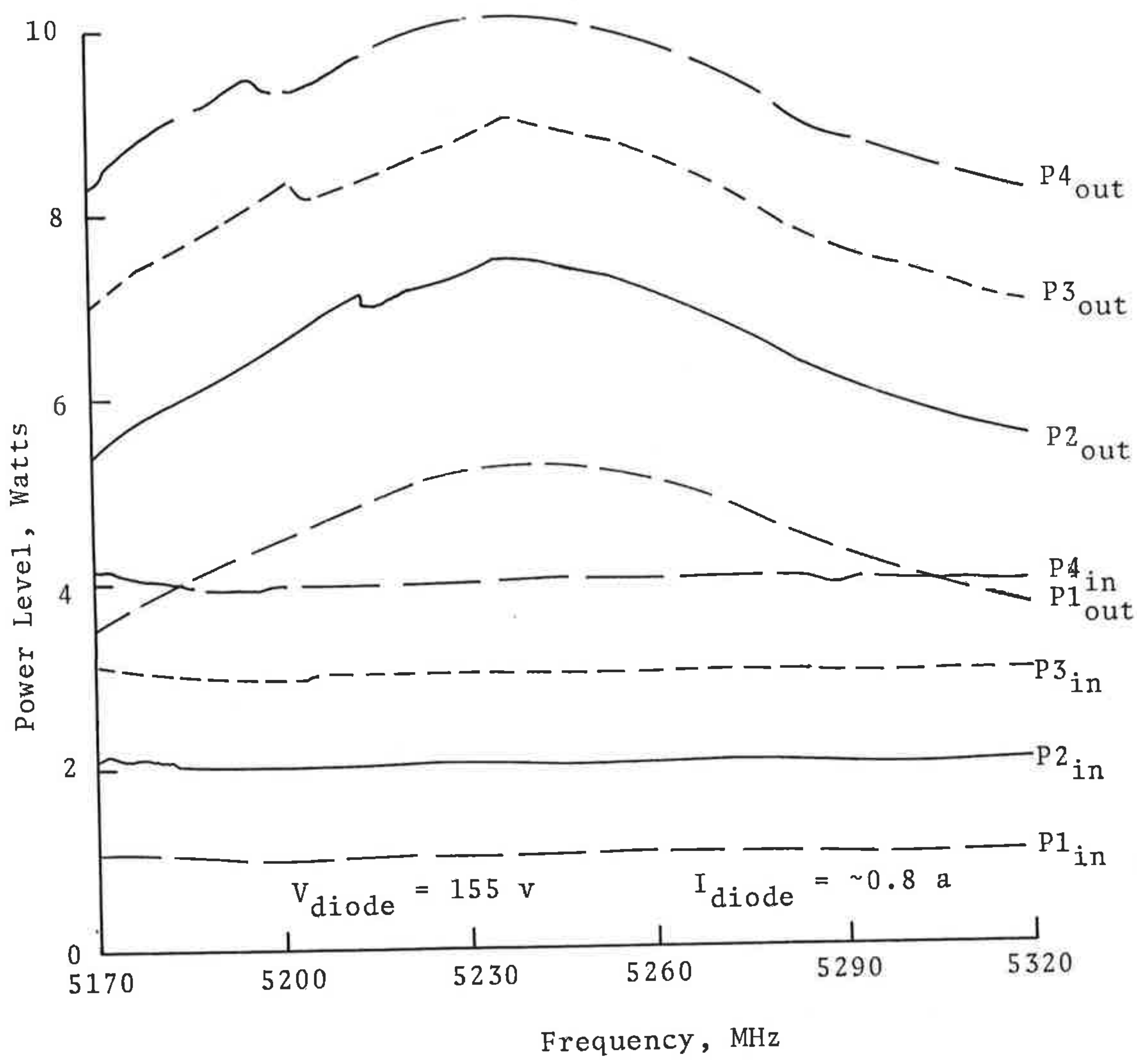


Figure 4 Impatt Amplifier Input/Output Characteristics

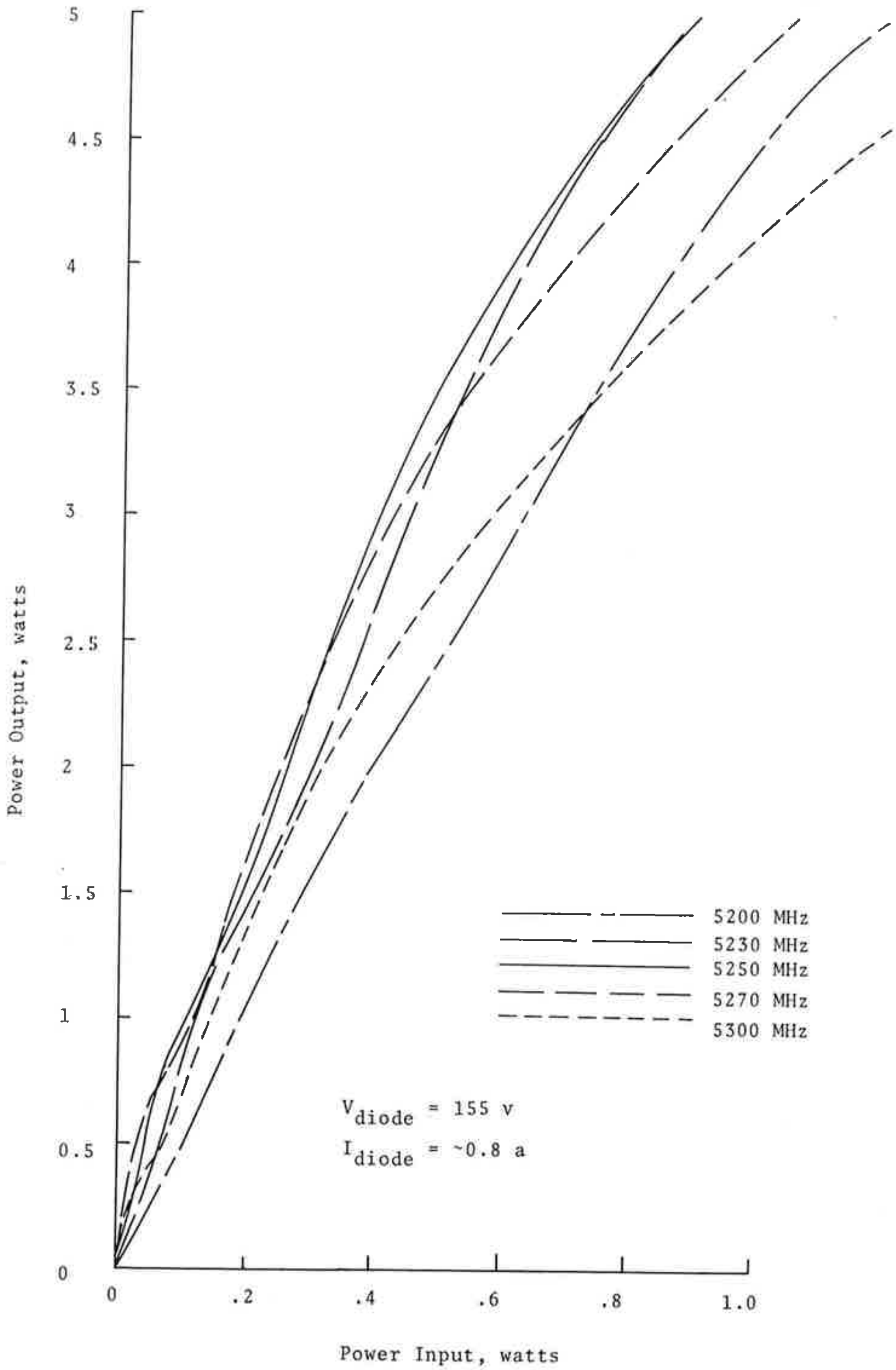


Figure 5 Impatt Amplifier Gain Linearity Characteristics

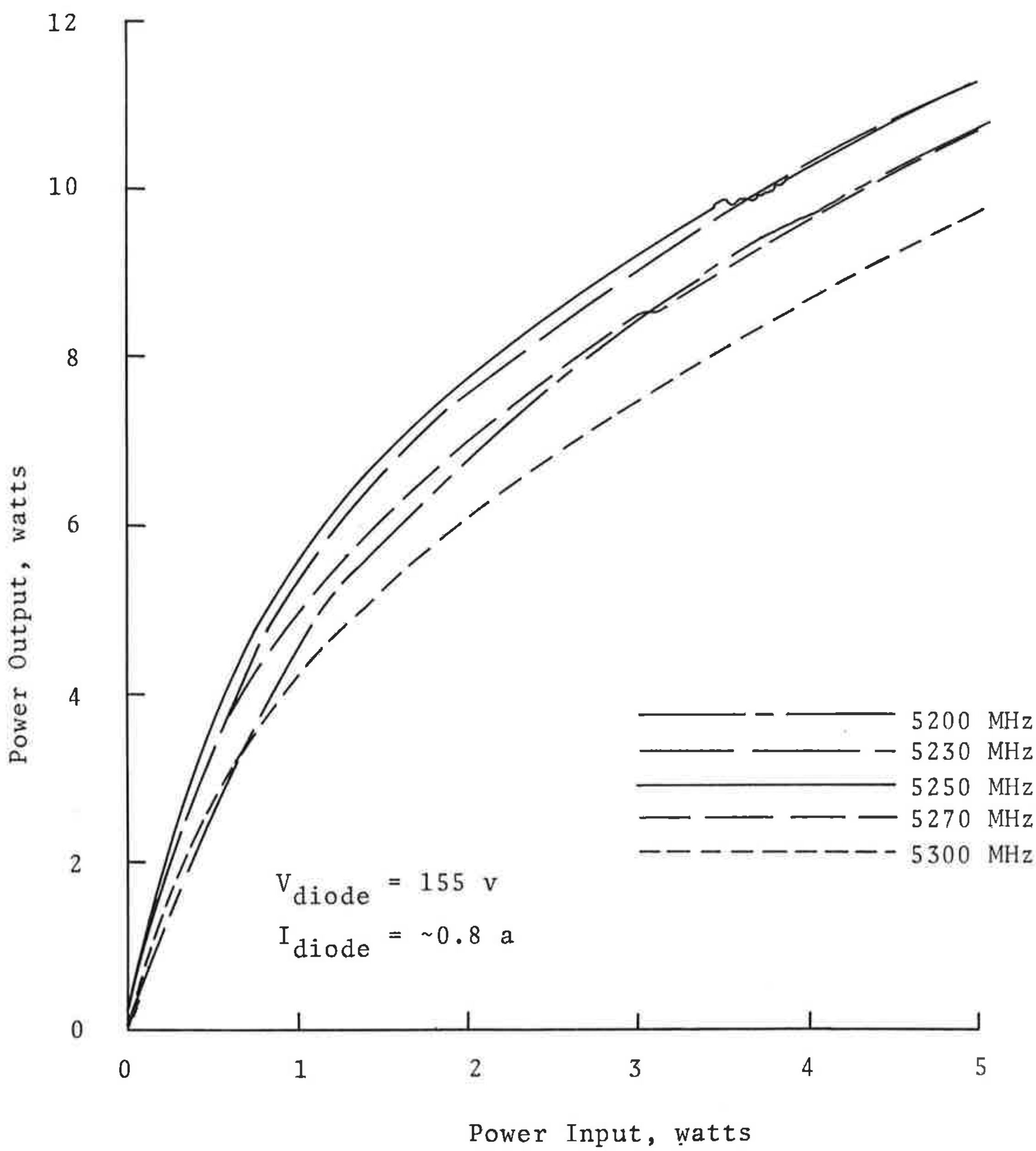


Figure 6 Impatt Amplifier Gain Compression Characteristics

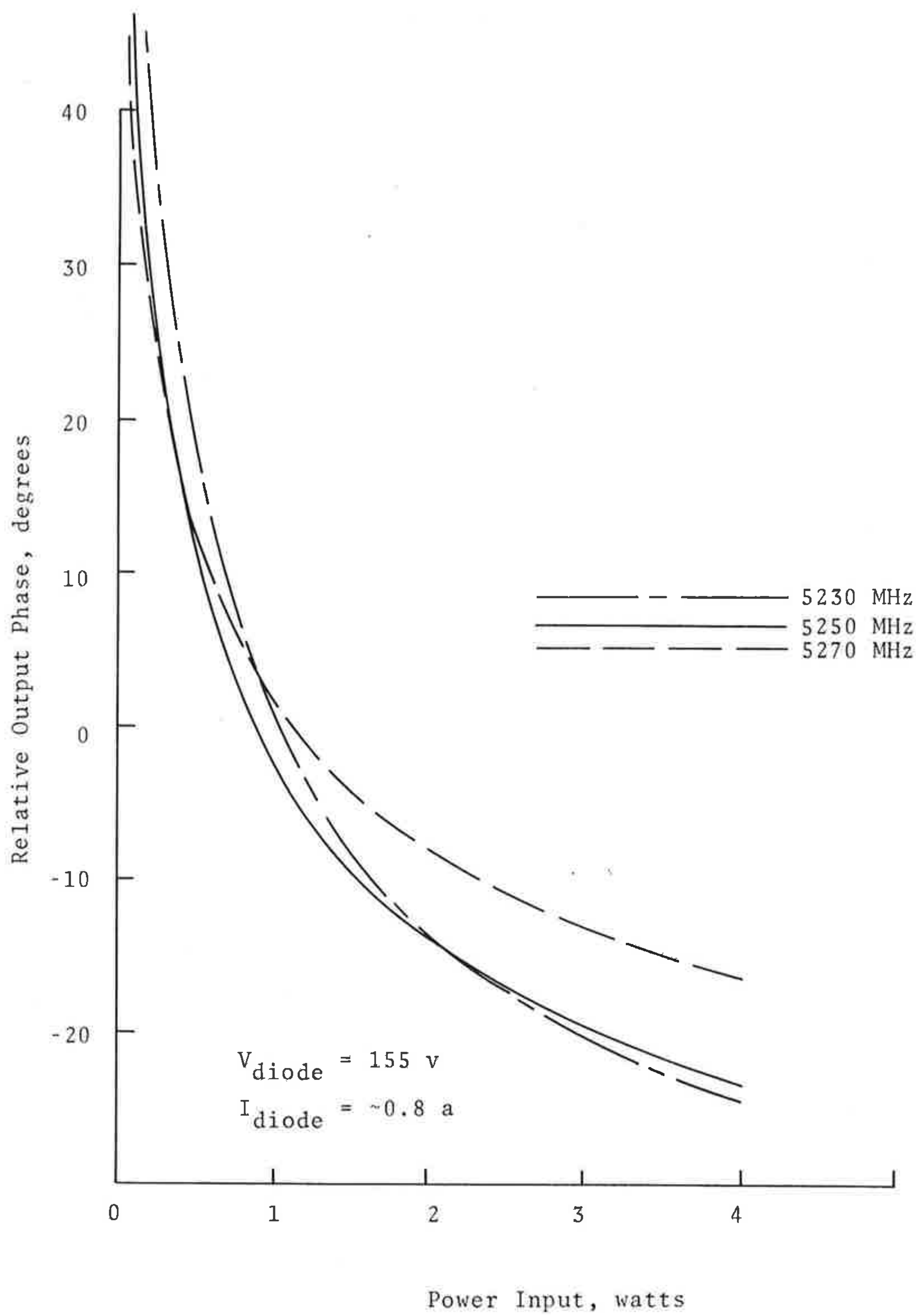


Figure 7 Impatt Amplifier-Phase Characteristics vs. Input Power

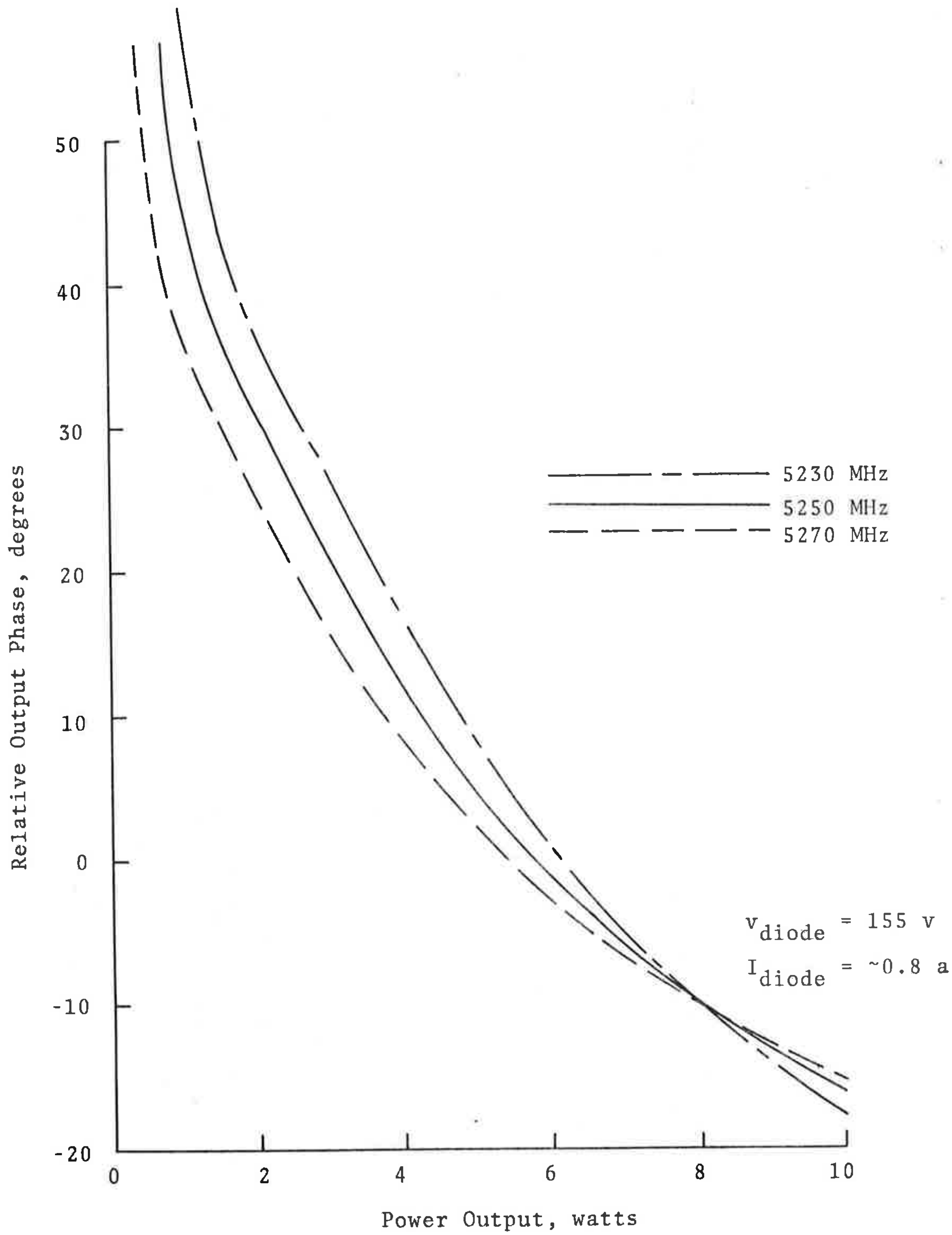
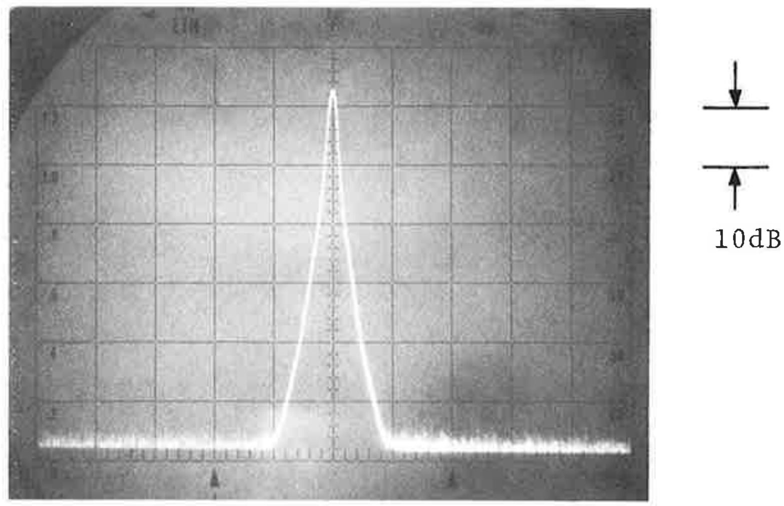
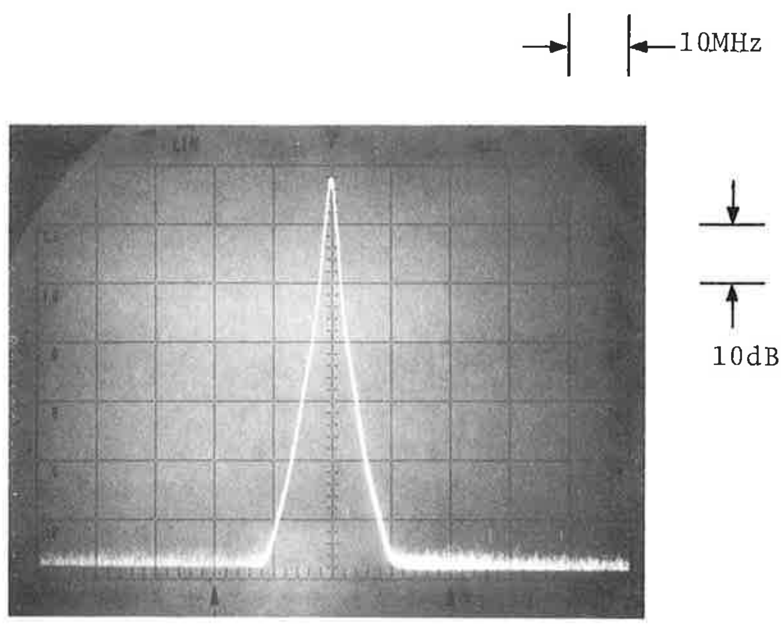


Figure 8 Impatt Amplifier-Phase Characteristics vs. Output Power



(a) Signal Into Impatt Amplifier



(b) Signal Out of Impatt Amplifier

Figure 9. Eight-Watt Impatt Amplifier Signal Coherence

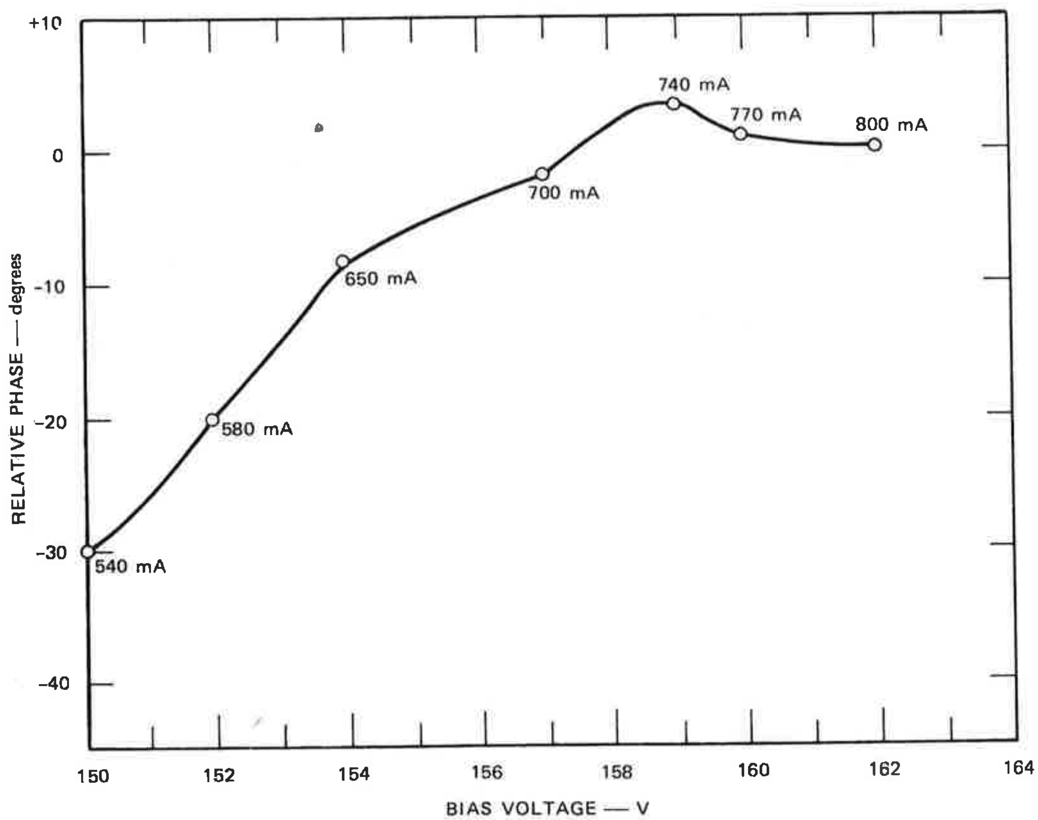


Figure 10 Phase Sensitivity of Four-Diode Amplifier to Supply Voltage Variation

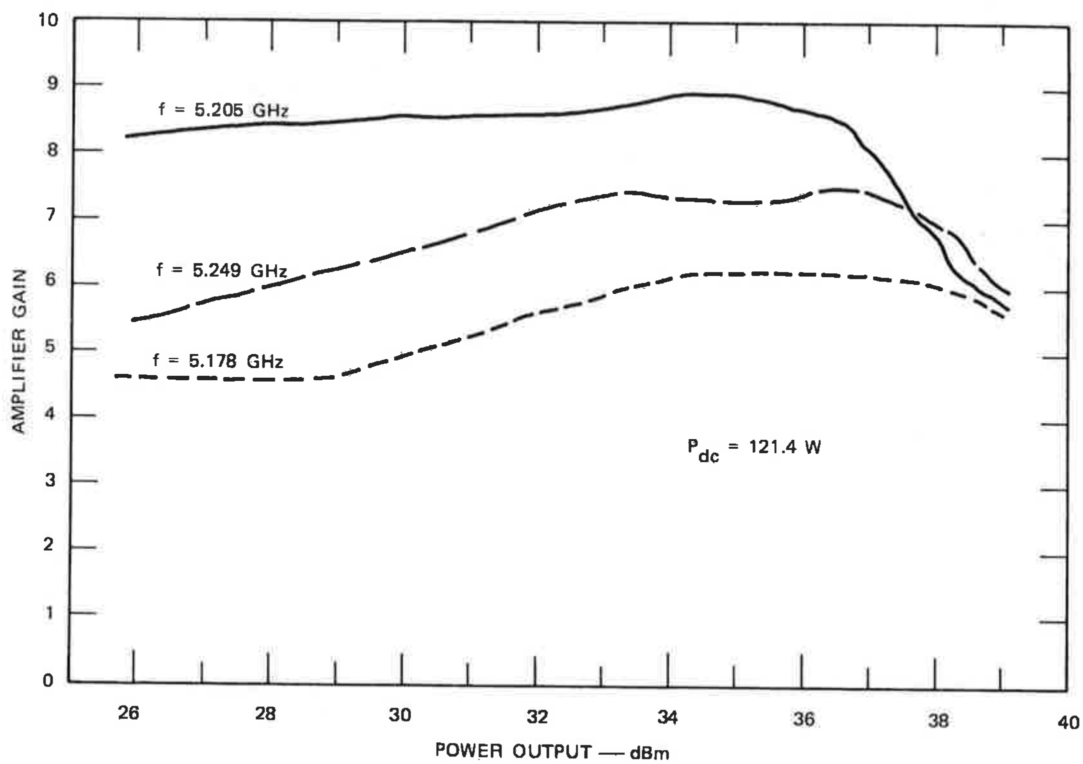
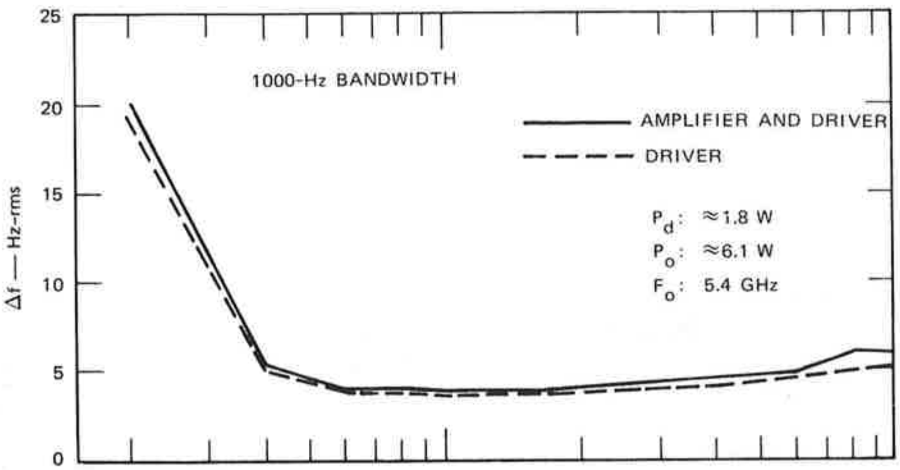
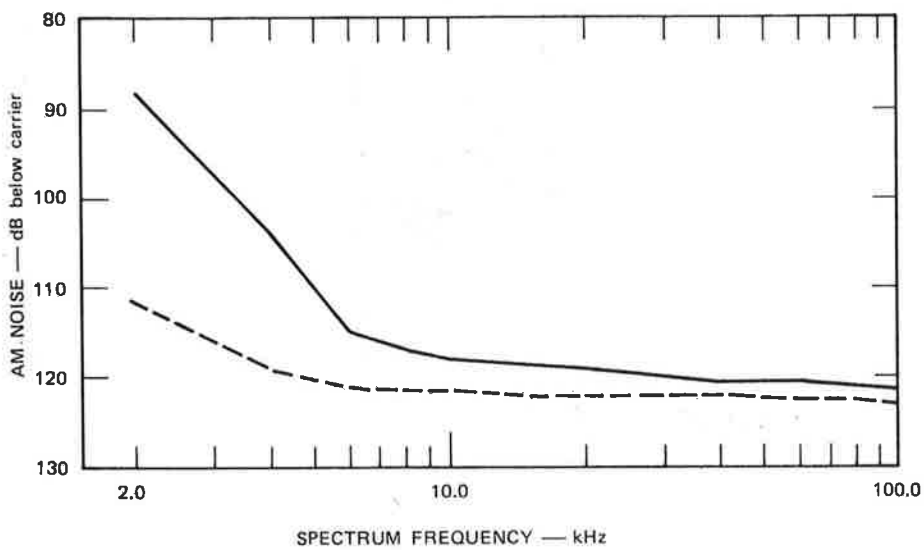


Figure 11 Gain Variation of Four-Diode Amplifier with Output Power



(a) FM Noise vs. Spectrum Frequency



(b) AM Noise vs. Spectrum Frequency

Figure 12 Comparison of FM and AM Noise Measured on a Low-Noise Klystron Driver and on Four-Diode Impatt Amplifier-Driver Combination

Figure 13 High-Power Avalanche Diode Amplifier

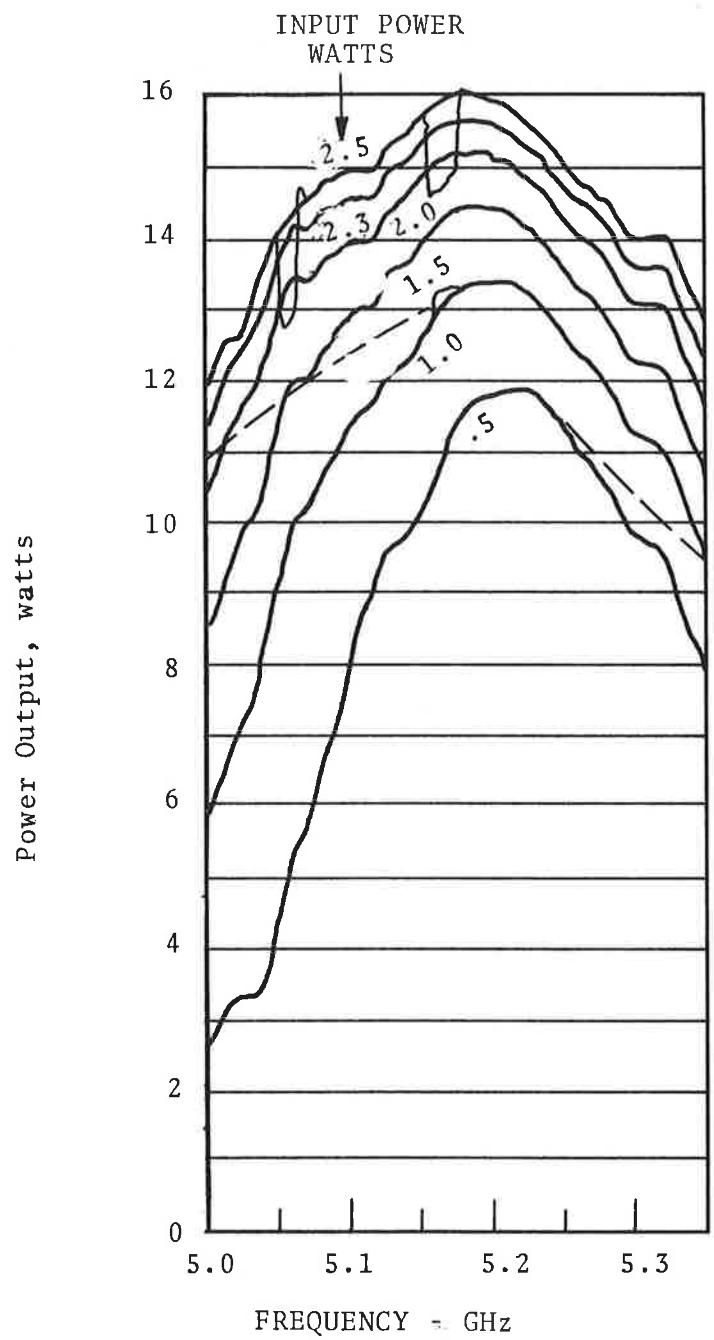


Figure 14 Frequency Response of High-Power Avalanche Diode Amplifier

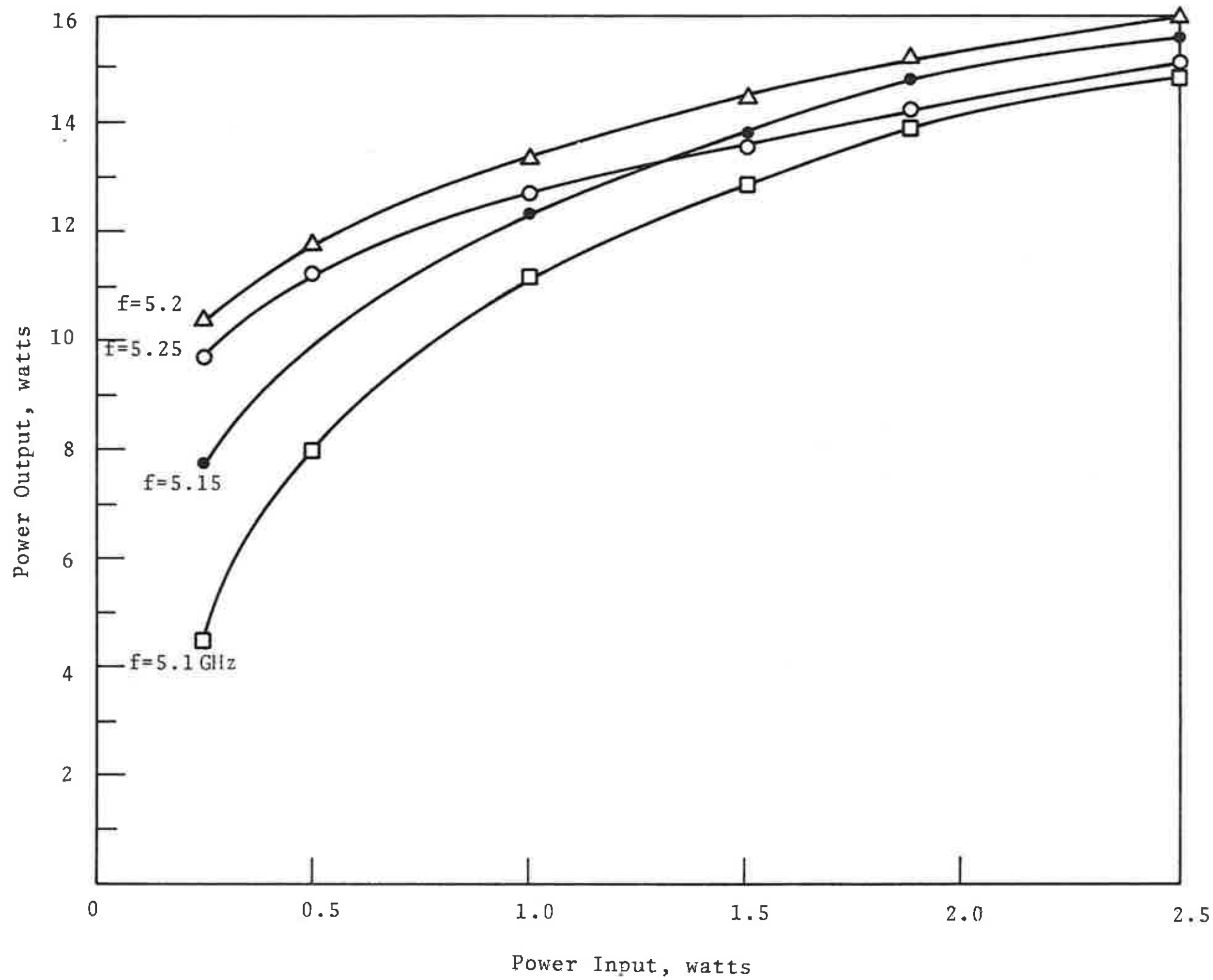


Figure 15 Power Response of High-Power Avalanche Diode Amplifier

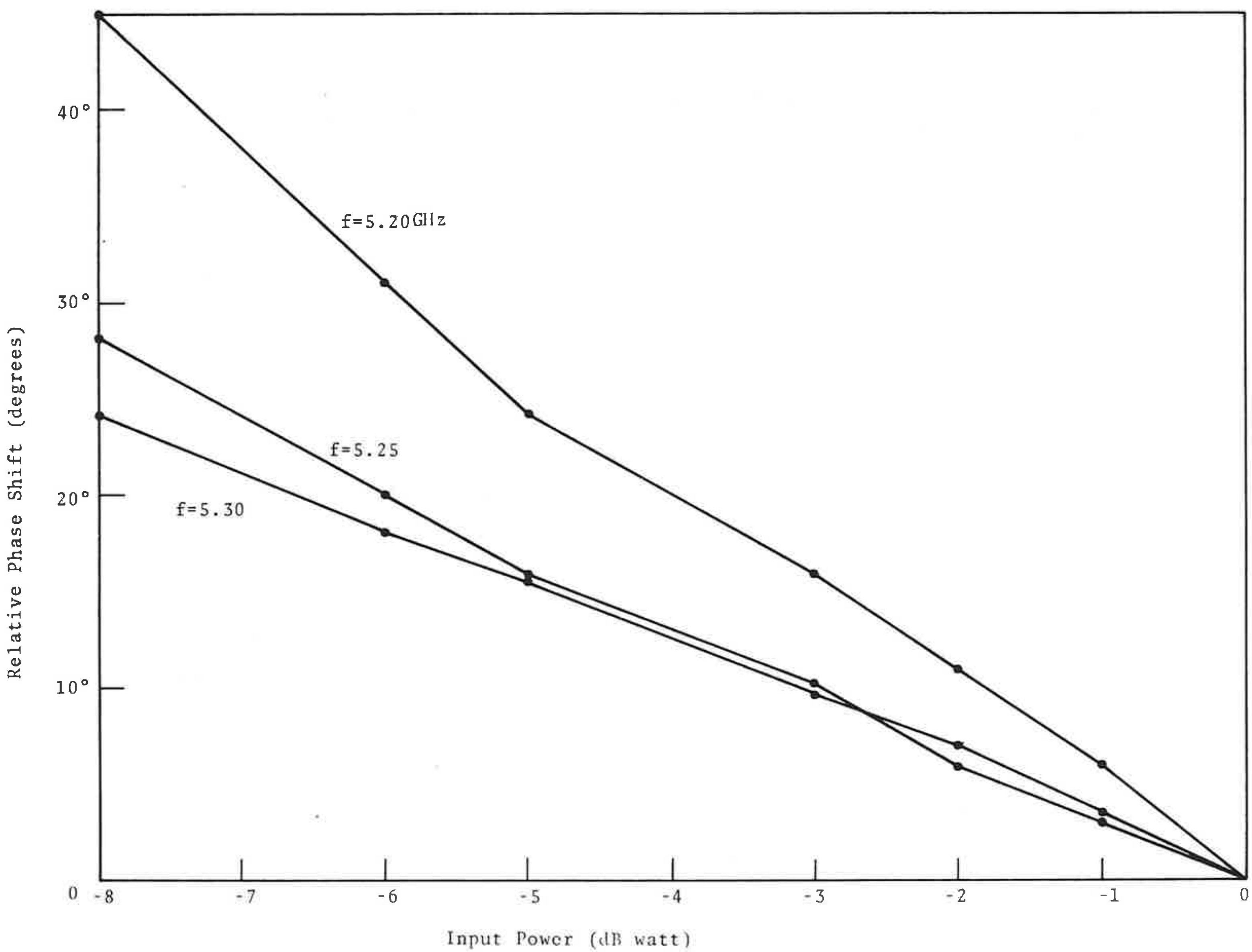


Figure 16 Phase Shift Through Amplifier At Various Input Powers

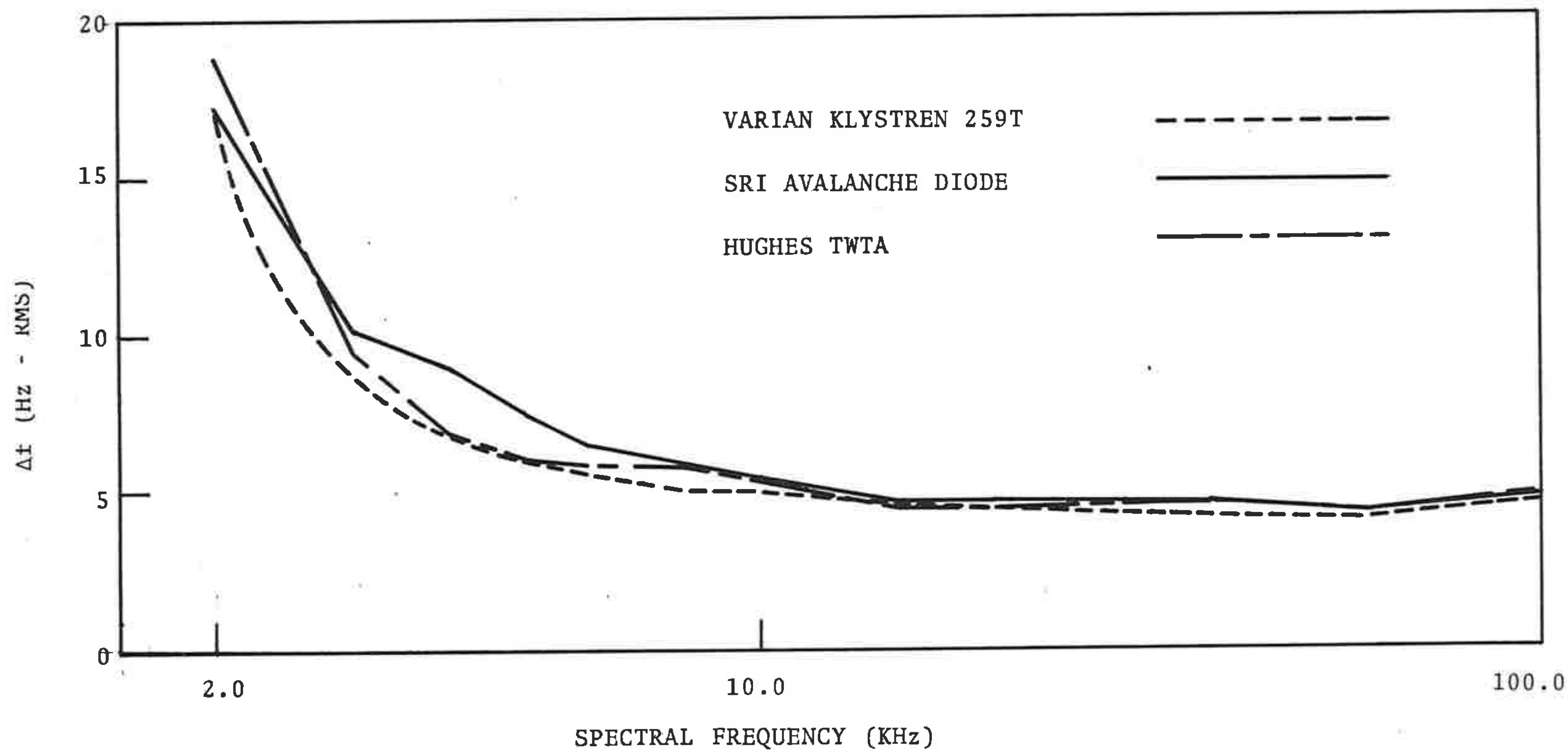


Figure 17 Measured FM Noise of the High-Power Avalanche Diode Amplifier Compared to a Klystron Oscillator and 10-Watt Traveling Wave Tube Amplifier, 1000 Hz Bandwidth

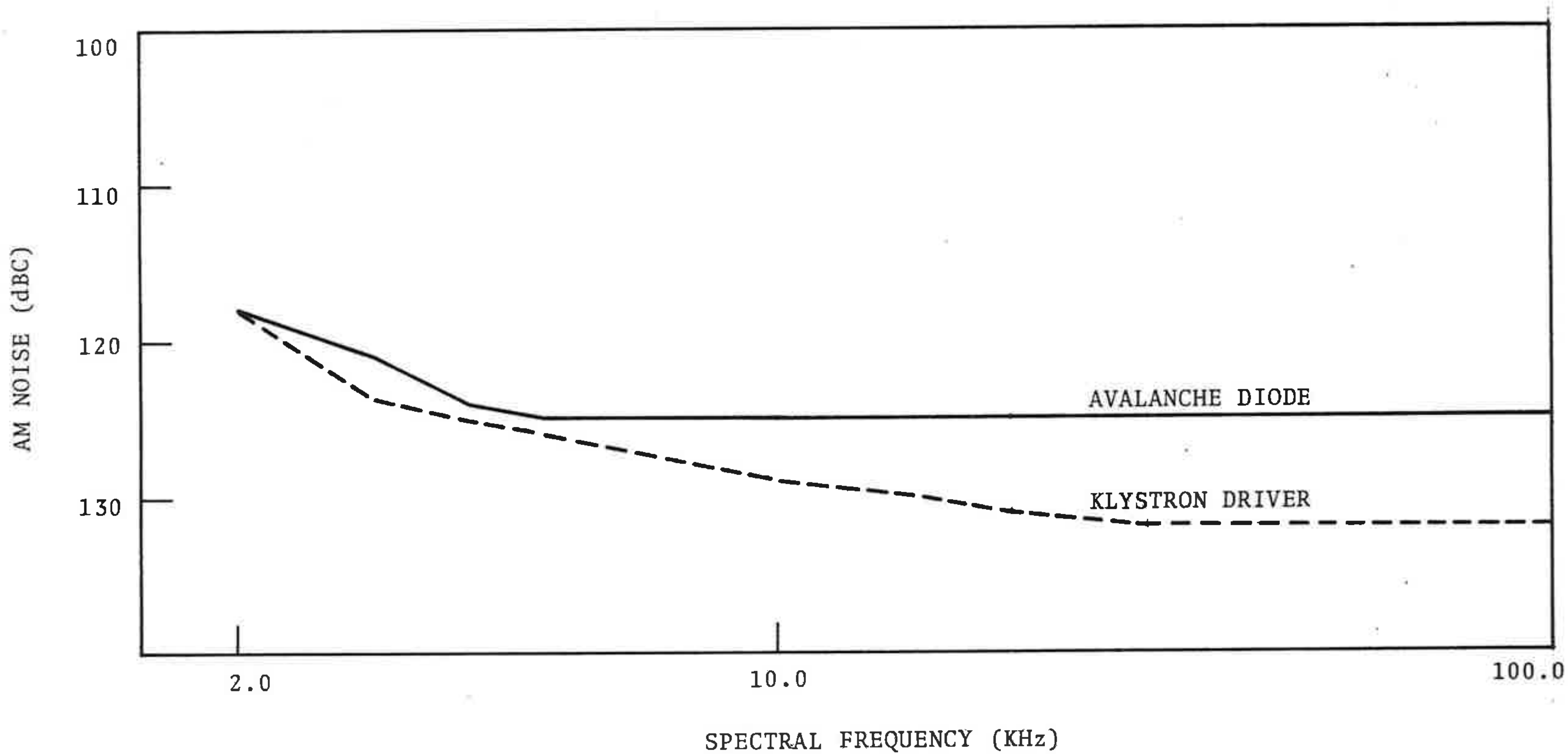


Figure 18 Measured AM Noise of the High-Power Avalanche Diode Amplifier Compared to Klystron Driver, 1000 KHz Bandwidth

TABLE 1. SILICON IMPATT AMPLIFIER-BASIC REQUIREMENTS

(1) Operating Mode: Unconditionally Stable Amplifier,

(2) Frequency: 5.19 ± 0.02 GHz

(3) Power Output: 4 Watts min.

(4) Efficiency: 5% min.

(5) Gain: 6dB min.

(6) Noise Pedestal: From 5.0 to 5.25 GHz to be 60 dB below output signal.

TABLE 2. MEASURED FM DISTORTION FOR THE FOUR-DIODE AMPLIFIER

Modulation Frequency f_m (MHz)	Modulation Index (β)	FM Distortion (percent-less than)
20	0.2	1.0
	0.4	1.0
	0.6	1.5
	1.4	1.5
40	0.2	1.0
	0.4	1.0
	0.6	1.5
	1.4	1.7
60	0.2	1.0
	0.4	1.7
	0.6	2.0
	1.4	1.7

TABLE 3. SPECIFICATIONS FOR HIGH POWER C-BAND IMPATT AMPLIFIER

1. Output Power: 16 watts minimum; 20 watts minimum design goal
2. Input Power: 2 watts maximum; 1.6 watts maximum design goal
3. Gain: 9 dB; 10 dB design goal
4. Bandwidth (1 dB points): 5.0 to 5.25 GHz; 4.9 to 5.35 GHz design goal
5. Parameter optimization frequency: 5.19 ± 0.02 GHz
6. Efficiency: 3.75% minimum; 5% design goal
7. Spurious: 2nd Harmonic -- 40 dB down from maximum output signal level
   2nd Harmonic -- 60 dB down from maximum output signal level when a reduction of 0.25 dB is allocated for insertion loss of filtering.
   Non-second Harmonic -- 60 dB down from maximum output signal level
8. Noise Pedestal: 60 dB down from the maximum output signal level
9. FM Noise: To be measured
10. AM Noise: To be measured
11. Ambient Operating Temperature Range: 0°C to +50°C; -30°C to +50°C design goal
12. Ambient Humidity: 0 to 95%; 0 to 100% design goal
13. DC Input Parameters: 200 volts maximum, 4 amps maximum
14. Reverse Polarity Protection: To be provided internally
15. Weight: Under 20 lbs.